Spawning and Rearing Atlantic Menhaden[1]

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ABSTRACT: Two-year-old Atlantic menhaden (*Brevoortia tyrannus*) held in the laboratory at ambient temperatures and salinities for more than 1 year, were induced to spawn by injecting first human chorionic gonadotropin and then carp pituitary powder. Spawning took place at temperatures of 16 to 20°C in a 2,100-L indoor tank modified to recover the buoyant fertilized eggs. Larvae were reared to the juvenile stage on a diet of cultured rotifers (*Brachionus plicatilus*), sieved wild zooplankton (64 to 500 μm), brine shrimp (*Artemia salina*) nauplii, and powdered trout food.

Atlantic menhaden (*Brevoortia tyrannus*) are economically the most important marine clupeoid along the Atlantic Coast of the United States. They are second by weight only to Gulf menhaden (*B. patronus*) in the United States fisheries, with an average annual catch of about 340,000 metric tons (Fisheries of the United States 1979). However, little information is available on early life history and factors affecting year class strength (Reintjes 1969; Kendall and Reintjes 1975). Difficulty in obtaining eggs and larvae has been a major factor in discouraging laboratory studies. The present investigation was designed to develop culture methods to alleviate that problem.

Spawning by captive menhaden has not been reported. Ferraro (1980) described the effects of temperature and salinity on the rate of embryonic development of eggs artificially fertilized from one female Atlantic menhaden captured in Long Island Sound. Henry and Kutkuhn (1970) reported the first laboratory rearing of Atlantic menhaden from gastrula-stage eggs to 10 mm; the eggs were taken in November 1968, 24 km south of Beaufort Inlet, North Carolina. Reintjes (1962) and Hettler (1968, 1970) reported artificially fertilizing eggs of the commercially insignificant yellowfin menhaden (*B. smithi*) and rearing the larvae, and Houde and Swanson (1975) reported rearing this species to the juvenile stage.

Materials and Methods

Juvenile menhaden (fork length, 80 to 100 mm) were collected from Bogue Sound, North Carolina, in September 1978. They were held in the laboratory for about 15 months at ambient temperatures (annual range, 5 to 28°C) and salinities (about 25 to 35 °/oo), in flowing sea water and under a natural photoperiod. The fish were fed granulated trout food daily and probably obtained additional food from the unfiltered sea water flowing into the tank. The lengths and weights of the 2-year-old fish are given in Table 1.

Efforts to induce spawning began in November 1979 (Table 1). Both sexes received intraperitoneal injections of human chorionic gonadotropin (HCG) and acetone-dried commercial carp pituitary powder suspended in a carrier of distilled water, administered at a point midway between the pelvic girdle and anus. The fish were anesthetized with tricane methanesulfonate before hormones were injected. Intramuscular injections were tried for the pituitary suspension, but the volume of liquid (1 mL) and the size of the hole left by the needle (16-gauge) caused most of the hormone to leak out of the fish. This problem was reduced by intraperitoneal injection.

The fiberglass spawning tanks used had capacities of 350, 670, and 2,100 L; the smallest tank was rectangular, the two larger tanks were cylindrical. Because the filter-feeding menhaden were not expected to stop feeding after spawning, a separate egg-collecting tank was provided to reduce egg predation. A 350-L tank received the outflowing spawning-tank water that contained the buoyant, fertilized eggs (Fig. 1). This tank had a water outlet in the shape of an inverted "U" that was screened with 500-μm nylon mesh to prevent loss of eggs.

Fertilized eggs were skimmed from the surface of the egg-collecting tank and washed in a 2-L separatory funnel several times with 34 °/oo filtered sea water. At this salinity the viable eggs floated, and dead eggs and waste particles could be removed. In the first rearing experiment, about 10,000 eggs were placed in the rearing tank (capacity, 670 L) with 250 L of 34 °/oo

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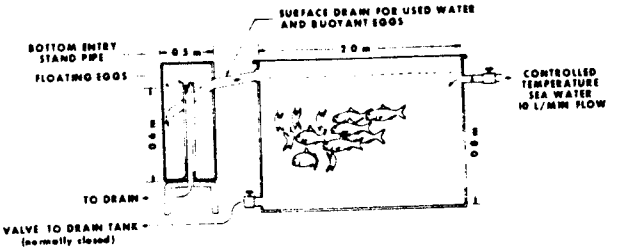

Fig. 1. Side view of the 2,100-L spawning tank and the 350-L egg-collecting tank.

sea water and a 7-mg/L prophylactic dose of Furan-2 (an antifungal compound containing nitrofurazone, furazolidone, and methylene blue). The rearing tank was initially stocked with 12 L of *Chlorella* algae and *Chlorella*-fed rotifers (*Brachionus plicatilus*) at a concentration of 5/mL. Algae and rotifers were produced as described by Hettler and Powell (in press). Rotifer concentrations were determined by averaging counts of 1-mL samples taken at the surface, middle, and bottom of the tank. Temperatures during rearing were increased slowly from 15°C in April to 28°C in August and then decreased to 15°C by November. A photoperiod of 16L:8D was used initially and then modified to 12L:12D; light came from a 300-W incandescent bulb mounted 0.8 m above the surface of the water. Conditions for subsequent rearing efforts were similar, except that 100-L tanks were used and rearing temperature was usually maintained at 20°C.

After hatching, which took 60 to 70 h at 15.5°C,

Table 1. Results of attempts to spawn Atlantic menhaden, 1979 and 1980.

Date and number of fish	Average standard length (mm)	Average wet weight (g)	Hormones injected (per fish)	Tank size (L)	Temperature (°C)	Results
1979						
1 Nov. 9	159	80	HCG (300 IU in 3 doses over 4 days)	2,100	20	No gametes
1980						
8 Jan. 12	179	132	HCG (450 IU in 3 doses over 4 days)	2,100	20	No gametes
26 Feb. 10	184	179	HCG (200 IU) Pituitary (30 mg)	350	20	Did not spawn; artificial fertilization unsuccessful, four females running ripe
11	182	183	HCG (100 IU) Pituitary (30 mg)	350	20	Did not spawn; artificial fertilization unsuccessful, five females running ripe
11	187	180	HCG (600 IU in 3 doses over 3 days)	350	20	Only two males ripe
11	185	169	HCG (300 IU in 3 doses over 3 days)	350	20	Only one male ripe
29 Feb. 43	(All fish from 26 Feb. test were transferred to a single tank)			2,100	20	Spawned; fertilized eggs recovered, not reared
7 Apr. 13	174	142	Pituitary (40 mg)	670	17	Shed eggs; did not fertilize
14 Apr. 9	178	145	HCG (200 IU) Pituitary (30 mg)	2,100	16	Spawned; larvae reared
27 Apr. 14	178	150	HCG (200 IU) Pituitary (30 mg)	2,100	18	Spawned; larvae reared
27 May 17	170	87	HCG (200 IU) Pituitary (30 mg)	2,100	23–19	No gametes
24 Sept. 9	196	195	HCG (250 IU) Pituitary (30 mg)	2,100	18	Spawned; larvae reared
17 Oct. 8	189	188	HCG (250 IU) Pituitary (30 mg)	2,100	18	Spawned; larvae reared
29 Oct. 9	195	190	HCG (250 IU) Pituitary (30 mg)	2,100	18	Spawned; larvae reared

larvae did not begin feeding for 4 days. First feeding occurred when the yolk was almost totally absorbed, the eyes were pigmented, and the mouth was functional. Larvae 5 days old began feeding on rotifers, which were kept at concentrations averaging 10 mL by the addition of a known number of rotifers after first determining the concentration of rotifers in the rearing tank each day. When larvae had grown to 8 mm (11 days), unidentified wild plankton, sieved through a 202-μm mesh and retained on a 64-μm mesh, were added to the tank daily. Rotifers were not added after the larvae reached 10 mm (15 days after hatching). A combination of wild plankton sieved through 500-μm mesh, brine shrimp nauplii, and powdered trout food (ground with a mortar and pestle) were fed to the larvae daily until 30 days after hatching. Throughout this period, a light green *Chlorella* bloom existed in the static rearing tank. Water volume in the rearing tank was slowly increased to 670 L by day 30, after which the static system was changed to a flowing system. New sea water entered the tank at a rate of 3 L/min and excess water left the tank through a screened standpipe. The concentration of larvae was estimated to be 3/L 30 days after hatching. From day 30 until day 65, when about one-half of the fish had reached the juvenile stage (about 25 mm, standard length), they were fed dry trout food and brine shrimp nauplii. As juveniles they were fed only trout food.

Results and Discussion

Five successful spawnings occurred, from which larvae were produced (14 and 27 April, 24 September, and 17 and 29 October 1980; Table 1). Spawnings occurred after each fish in a spawning group was given a single injection of HCG (200–250 IU) followed 24 h later by a single injection of carp pituitary powder (30 mg). Ovulation or spawning was not induced by either single or repeated injections of HCG alone. Pituitary powder alone caused ovulation and egg release, but no fertilization. It is not clear, however, whether the hormone treatment was insufficient to produce viable gametes or whether the tank size (670 L) inhibited spawning behavior. Tank size (350 L) apparently inhibited spawning of the groups treated on 26 February. Although the region of the gonads was swollen in these fish and they appeared ready to shed gametes, no eggs were recovered on the outflow screen. These fish were manually stripped during the day after it appeared that spawning would not take place. Eggs and milt flowed easily with slight abdominal pressure, but the few thousand eggs that were taken from the ripe females were not receptive to fertilization. This lack of fertilization is probably due to a diurnal periodicity in optimum ripeness of the eggs. On 29 February the 43 fish treated beginning 26 February were moved to the 2,100-L tank and spawning occurred that night; time of spawning was estimated to be 0300 h. An extended power failure resulted in the loss of all these fish and the eggs, due to extremely cold water temperatures on 1 March.

Cold temperatures experienced during early March by virgin spawning stock located in another building did not end the spawning potential for the season. The April spawning groups survived temperatures as low as 5°C for several days as a consequence of the power failure and experienced temperatures between 6 and 12°C until 2 weeks before eggs were successfully produced. An attempt to spawn the remaining menhaden was not successful (27 May). These fish had not been selected for earlier spawning attempts because of their small size; not only were they still smaller, but the temperature in the holding tank had risen to 23°C by this time. Three days before hormones were to be injected, the water temperature was slowly lowered to 19°C. Examination of gonads following this attempt showed that ovaries and testes had regressed to a resting stage; the eggs were less than 0.5 mm in diameter.

Following a summer season during which the used spawners were held at temperatures of 25 to 30°C, they were slowly acclimated to 19°C by 18 August at a rate of 2°C per day. A group of nine fish treated with HCG and pituitary powder spawned on 24 September and the resulting larvae were reared. The success of this approach suggests that it may be possible to maintain menhaden in the laboratory that would be ready to spawn at any time during the year either by (1) maintaining two stocks of spawners, one at water temperatures higher than 25°C (when the gonads rest and recover from gamete production) and the other at spawning temperatures of 16 to 20°C, or by (2) maintaining one large stock of menhaden year around at spawning temperatures. Previous experience with spot (*Leiostomus xanthurus*), however, suggests that it may not be possible to keep fish in spawning condition year around by holding them at spawning temperatures (Hettler and Powell in press). Held at constant spawning temperatures, spot could not be induced to spawn for longer than an 8-month period without an intervening "summer" recovery period of long day lengths and warm temperatures.

The effect of intensive feeding (fed to satiation three times daily), nearly constant temperature (20°C) sea water, and HCG on the maturation of gonads was compared with menhaden that experienced only maintenance feeding (fed once daily), fluctuating, decreasing temperatures (average 13°C), and no hormone injection (Table 2). The gonadal index (ovary pair wet weight divided by total body wet weight) was significantly higher ($P \leq 0.05$) for intensively fed females at 20°C than for those on the maintenance diet and decreasing temperature regime. Egg diameter was also significantly larger ($P \leq 0.01$) from fish in the intensive

diet and warmer temperature regime. The greater length and weight of this group is probably due to both temperature and feeding conditions, but the increased egg and ovary size may be due to hydration as a result of the HCG.

Photoperiod was not considered an important pre-spawning condition because Atlantic menhaden spawn throughout the entire year. When menhaden spawn at latitude 28°N during the winter, the photoperiod is 10L:14D, but when they spawn at latitude 42°N during the summer, the photoperiod is 15L:9D. Thus, the photoperiod may not need to be precisely regulated in the laboratory to promote spawning of this species.

Larvae were reared to the juvenile stage (about 25 mm standard length) in 2 months at an average temperature of 20°C. By the middle of October, 6 months after hatching, a sample of juveniles had a mean wet weight of 18.4 g and a mean standard length of 92.2 mm. In one rearing tank from an estimated 10,000 eggs, about 2,000 larvae were alive after 30 days and about 400 juveniles remained at the end of October. More than 800 fish were removed from this rearing tank during the rearing period for development and physiology studies. A high incidence (about 20%) of fish in the 14 April spawn were anomalous, primarily pug-headed or with shortened opercula or both, and juvenile transformation of these anomalous individuals was retarded. This condition was attributed to a pug-headed adult noted to be among the nine spawners. No catastrophic mortalities occurred during rearing. Predation by chaetognaths (*Sagitta hispida*) on larvae smaller than 11 mm was observed. The chaetognaths had been accidentally introduced into the rearing tanks when wild plankton was added and were individually removed when they were observed.

Rotifers were not essential in rearing the first-feeding larvae, although they probably afford a more reliable energy supply than sieved wild plankton. In one tank, about 2,000 larvae were reared to the juvenile stage with 50% survival on sieved wild plankton (64 to 202 μm), brine shrimp nauplii, and powdered trout food (the amount of each dietary component was not measured). Brine shrimp and trout food were not supplied until the larvae were 10 to 12 mm. Larvae preferred feeding on brine shrimp nauplii, but by 15 mm they had adapted to striking at and consuming finely ground trout food floating at the surface or sinking through the water column. As juveniles, they were fed only trout food ("00" crumbles), the same diet as that fed to the spawners.

One behavioral trait of the larvae suggests that the walls of rearing tanks should not be clear, white, or light-colored. Larvae were attracted by white vertical surfaces (e.g., white plastic standpipes, tank walls incompletely covered with black pigment, or glass aquarium walls). When larvae approached a vertical white surface, they swam vigorously head-first against the surface. Black tank walls (and white tank bottoms) did not evoke the same response. Menhaden larvae also swam readily into a white bucket held under water in their rearing tank.

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Table 2. Effect of temeprature, intensive feeding, and HCG on body size, gonad size, and egg diameter over a 3-month period. The fish at 20° C on the intensive feeding regime are the 8 January group of Table 1; the fish at 13° C on the maintenance feeding regime were selected from a stock tank of extra fish.

Sex and number of fish	Temperature (°C)	Feeding regime	Average standard length[a] (mm)	Average wet weight[a] (g)	HCG	Gonadal index[a]	Mean egg diameter[b] (μm ± SE)
Male 6	20	Intensive	177	126	+	8.5	
Female 6	20	Intensive	182	139	+	9.8*	761** ± 8.64
Male 6	13	Maintenance	168	95	-	8.3	
Female 5	13	Maintenance	169	98	-	6.9*	668** ± 6.28

[a] At start a 10-fish subsample had a mean size of 160 mm, 80 g, and a gonadal index (gonad weight divided by body weight) of 3.2%.
[b] Egg diameters measured from 120 eggs at each temperature.
* Significantly different, based on *t*-test for unpaired data ($P \leq 0.05$)
** Significantly different, based on *t*-test for unpaired data ($P \leq 0.01$)

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